PENNSYLVANIA
GEOLOGICAL SURVEY
FOURTH SERIES

BULLETIN G 11

A PALEOZOIC SECTION

AT

DELAWARE WATER GAP

By

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TOPOGRAPHIC AND GEOLOGIC SURVEY
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Harrisburg, Pa.

1938

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INTRODUCTION

This bulletin is the second published by the Pennsylvania Topographic and Geologic Survey to serve as a guide to interesting geologic features of a particular part of the State. The first deals with the Susquehanna Valley (47)[1]. The Delaware Water Gap area here described, with supplementary remarks on adjacent areas to the west, consists of a narrow band running slightly west of north along the Delaware River and Brodhead Creek valleys from north of Slateford, Northampton County, to the vicinity of Analomink, Monroe County. It includes sections across Kittatinny Mountain and Godfrey Ridge, and it passes through the boroughs of Delaware Water Gap and the Stroudsburgs. The stratigraphic succession will be referred to in this bulletin as the Delaware Water Gap section.

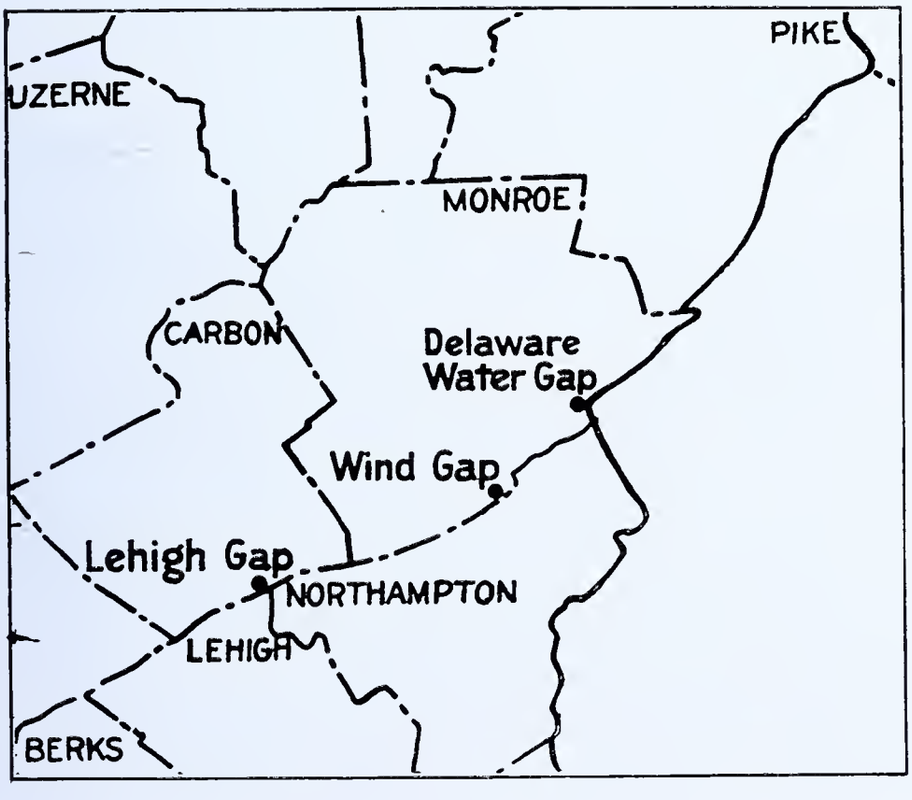

Figure 1. Sketch map showing location of section

The extreme northern corner of Northampton County touches the western rampart of Kittatinny Mountain at the Gap. Beyond, to the north, Monroe County includes the remainder of the section on

[1] Numbers in parantheses refer to the bibliography at the end of this bulletin.

the Pennsylvania side of the river. To the east, on the New Jersey shore, a complementary sequence matches in part that exposed in Pennsylvania. The following description is restricted to the geology observable from the entrance of the Gap north along the Pennsylvania side of the Delaware to its confluence with Brodhead Creek, and thence still northward, across Godfrey Ridge, through the Stroudsburgs to Analomink. Here the section conveniently ends in continental Devonian beds.

Particular mention is here made and acknowledgement given to F. M. Swartz of the Pennsylvania State College and A. B. Cleaves of the Pennsylvania Topographic and Geologic Survey. Dr. Swartz furnished data on the uppermost Silurian and the Helderberg group which have not been published and which greatly improve our understanding of this difficult part of the sequence. Dr. Cleaves furnished data on the Oriskany, and spent some time in the field checking the mapping of that sandstone, particularly in the valley of Brodhead Creek between Stroudsburg and North Water Gap.

Significance of Section

To those who have visited the Delaware Water Gap, a description of its scenery is superfluous. He who has paused of an August afternoon in the shade of its mountains, or who has delighted in its January

Figure 2. View of Delaware Water Gap looking southeast toward the New Jersey shore. Photograph by Geo. H. Ashley

whiteness, seen spring come to the alder bushes along the river's edge, or watched autumn's red and gold leaves float down the swift stream, has experienced some of the delights of the Delaware Water Gap.

Yet few, perhaps, are conversant with its geology; and rocks, after all, are the walls upon which are spread nature's frescos. Darwin once regretted that his understanding of the vocal mechanism of a bird detracted from his pleasure in its song. Let it be hoped that an understanding of the geology of the Water Gap may not mar the reader's appreciation of its scenery.

As long ago as 1858, Henry D. Rogers included a fairly detailed description of the geology of the Water Gap in his final report (21). After a lapse of a generation, I. C. White's revision of the older work appeared in 1882 as part of his account of the geology of Pike and Monroe Counties (33). This account remains today the most complete, single work on the area; but, excellent for its time, it is now obsolete where it discusses details of stratigraphy and stratigraphic nomenclature. Lesley summarized the Second Pennsylvania Survey's work for the region (11). Since White's day, several publications have appeared dealing piecemeal with the region or describing some particular feature or phenomenon. Johnson briefly summed up the whole section for the Sixteenth International Geological Congress (7). From the New Jersey Geological Survey emanated two books of special importance (9, 32). In them are descriptions of the Paleozoic formations and their fossils from the New Jersey side of the Delaware. Both New Jersey (13) and Pennsylvania (19) have recently published State Geologic Maps. The former is the better, since the Pennsylvania map fails to revise locally much of the inaccurate, nineteenth century mapping and nomenclature. Incidental papers are several. Stose in 1930 briefly mentioned structures at the Gap (23). Schuchert (22), C. K. Swartz and F. M. Swartz (26, 27), Willard (34) and others have written on the Silurian in eastern Pennsylvania. By far the most important of these articles is the second by Swartz and Swartz. Of the Devonian, Prosser (20) first attempted to revise the work of White. During the past eight years, I have had the pleasure of studying the Devonian of Pennsylvania, and have published a few papers dealing with the subject. Of these, some (35, 36, 38-44, 46) bear directly upon the Delaware Water Gap region. Parenthetically, it may be noted that this area was the subject of my doctor's dissertation. A few additional papers touch upon the glacial and physiographic aspects of the section (1, 12, 30, 31).

Drainage and Topography

The Delaware River is the master stream of the area. Northeast of Delaware Water Gap village, its course is southwest by west, but near that point it turns sharply south by east and winds down through the Gap. Into the Delaware flow several tributary streams, three of

fair size. Dunnfield Creek plunges down to the river on the New Jersey side about a mile above the Gap. Cherry Creek meanders in from the west at Delaware Water Gap village, and Brodhead Creek joins the river a quarter of a mile farther north. Brodhead Creek itself ramifies into McMichael and Pocono Creeks at East Stroudsburg.

The Delaware Water Gap is cut by the Delaware River through Kittatinny (also called "Blue," "North," and "First") Mountain, a persistent ridge extending generally northeast and southwest for miles across New Jersey and Pennsylvania. The Delaware is but one of several rivers which have sawed their channels down through the hard rock ridge, but the sinuous gap of the Delaware is usually considered the most attractive. The Schuylkill, Lehigh and Susquehanna traverse the mountain more nearly at right angles. The fore (south) slope of Kittatinny Mountain is steep. Cliffs are common along the exposed edges of the north-dipping strata. From their bases slope great piles of talus. The gentler north slope conforms nearly with the dip of the beds. On the New Jersey side the land surface drops from 1,600 feet at the mountain crest to 400 feet above tide at the mouth of Dunnfield Creek. On the Pennsylvania side at the head of Poplar Valley, a 900-foot low point is attained. Thence, on each side the surface rises along the river in the low, broad swell of the Kemmererville anticline which trends parallel to Kittatinny Mountain Through this the river passes in a curving, deep-cut valley. Its rock walls doubtless are oversteepened in some places by ice action.[2] At Delaware Water Gap village the main valley of the river turns nearly at right angles northeast by east to Walpack Bend along a belt of non-resistant limestone and shale. Southwest by west, the valley of meandering Cherry Creek is bordered along its north side by a long, sharp hill called, locally, Godfrey Ridge. Through this ridge, which parallels Kittatinny Mountain, Brodhead Creek has cut a miniature water gap at Minnisink Mills, three-fourths of a mile north of the confluence of the creek with the Delaware. Above its small gap, the creek valley turns sharply west and follows the north flank of the ridge until Brodhead Creek makes confluence with McMichael and Pocono Creeks at the Stroudsburgs. Thence, Brodhead Valley cuts a little west of north toward the southern escarpment of the Pocono Plateau. Stroudsburg and East Stroudsburg occupy another east-west trending, soft rock belt, two to two and one-half miles wide, a region of low, irregularly distributed hills of shale and drift. Brodhead Creek Valley here expands to over a mile wide as it traverses a plain of fluvio-glacial debris, outwash sands and gravel banks. About a mile

[2] Prior to the widening of the highway along the Pennsylvania side of the river, abundant ice-grooving and polishing were preserved in the rock walls about one and one-half miles north of the gap, in the gap and along the trolley track.

north of Gravel Place the valley narrows, and bed rock appears from under the blanket of gravel and sand. Hard sandstone hills prevail; a pronounced northeast by east-trending escarpment marks their southern boundary. Northward, again, to and beyond the areal limits of this discussion, the relatively higher hills are veneered by drift. Eventually, farther to the north and northwest, the country rises above these along the steep face of the Pocono Plateau.

The Geologic Column

	Feet
PENNSYLVANIAN	
Pottsville conglomerate	
MISSISSIPPIAN	
Mauch Chunk red shale	
Pocono formation	
DEVONIAN	
Catskill continental facies. Several divisions are recognized, including	
Honesdale gray sandstone and over- and underlying red beds	3,000±
Delaware River flags	1,000
Analomink red shale	100
Portage group (marine facies)	
Trimmers Rock sandstone	1,000
Laurens member	50±
Hamilton group	
Mahantango formation	1,200
Moscow faunal facies	
Ludlowville faunal facies	
Centerfield coral reef	
Skaneateles faunal facies	
Marcellus formation	800–900
Onondaga group	
Buttermilk Falls limestone	200
Esopus shale	250
Oriskany group, undifferentiated	135?
Helderberg group*	
Port Ewen-New Scotland shale	226
Coeymans limestone	
Stormville sandstone member	15
Crystalline limestone	30
Keyser limestone	
Manlius limestone member	31
Rondout limestone member	15?
Decker sandstone member	92
SILURIAN†	
Bossardsville limestone	100?
Poxono Island formation	300?
Bloomsburg continental facies	1,800–1,900
Shawangunk formation	2,000
ORDOVICIAN	
Martinsburg formation	

* The data here given are based partly upon the report of F. M. Swartz (25), but chiefly upon his revision of the Helderberg in the Delaware Water Gap region, letter of April 14, 1938. It seems quite probable that the Keyser may be assigned to the Silurian eventually.

† The Bossardsville, Poxono Island and Bloomsburg, in part, are Cayugan; the lower part of the Bloomsburg and the Shawangunk are Niagaran and Medinan.

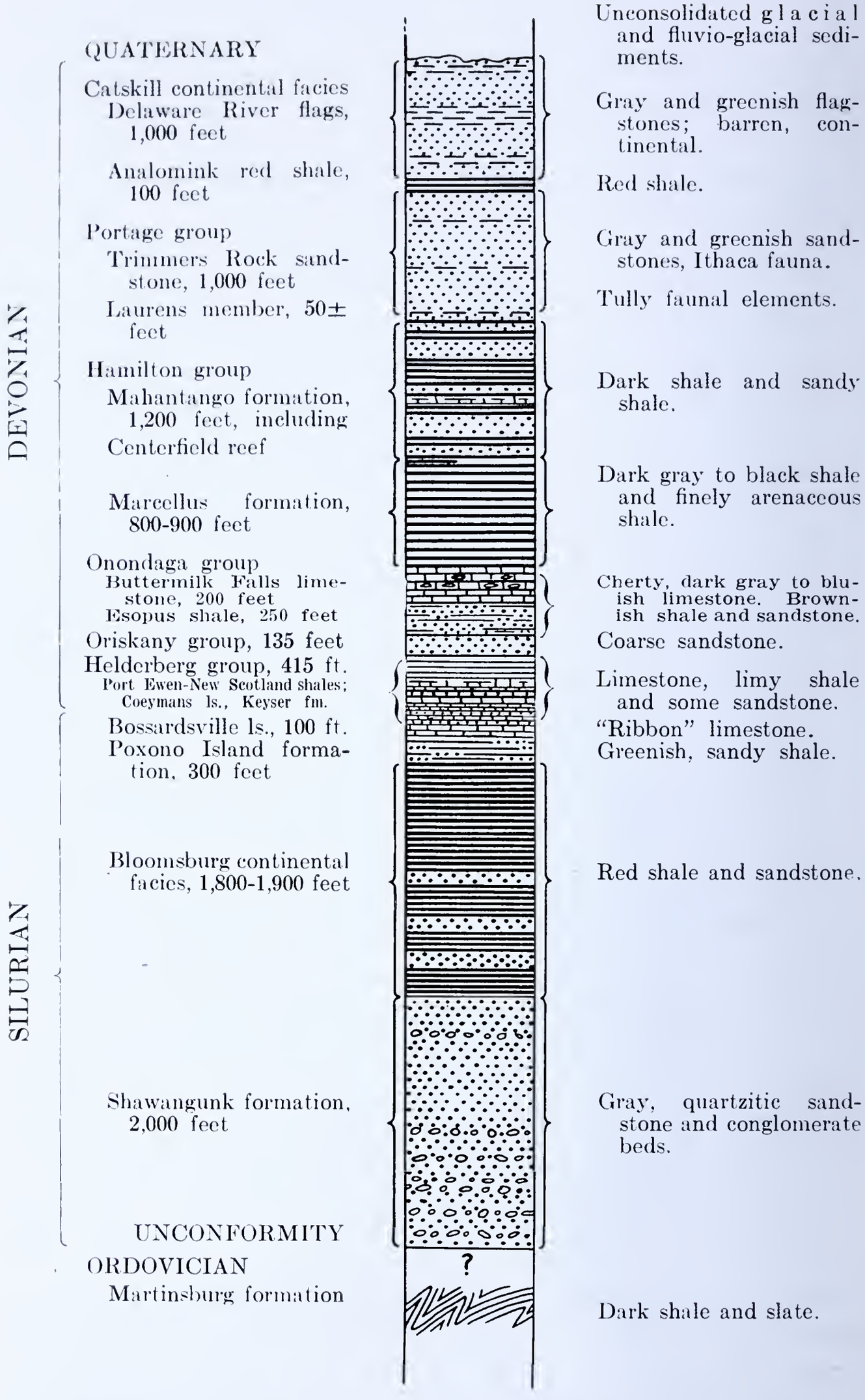

Figure 3. Geologic column for the Delaware Water Gap area.

STRATIGRAPHY

The northeast-by-east, southwest-by-west trend of the ridges and valleys in the Delaware Water Gap area is a direct expression of the trend of the formation outcrops, of the grain of the country rock. The region is underlain entirely by sedimentary rocks ranging in age from late Ordovician in the south through late Devonian in the north. Generally, gentle folding has imparted a comparatively low north to north-northwest dip to the strata, which is interrupted by occasional reversals. Consequently, exposures caused by long-continued weathering and peneplanation acquaint us with successively younger bands of rock from the Gap to the Plateau. Furthermore, through differential erosion, hard Silurian and Devonian units produce the outstanding topographic features, Kittatinny Mountain and Godfrey Ridge, and the scarps north of Stroudsburg and along the Plateau front. The soft shales of these systems floor the ridge-parallel valleys. A characterization of the several stratigraphic units, in chronologic sequence from the Ordovician upward as met from the south entrance of the Gap to the vicinity of the village of Analomink, precedes. In addition, units encountered in the Wind Gap and Lehigh Water Gap sections are appended.

ORDOVICIAN SYSTEM

The Ordovician system in eastern Pennsylvania is composed of limestone below and clastic sediments above. The higher beds are grouped under the inclusive term, Martinsburg formation, obviously a misnomer, considering their known diversity and probable thickness. In the region of the Delaware Valley, much of the dominantly shaly Martinsburg has been altered to slate. As such it was formerly extensively quarried here. Today, a few abandoned openings expose the slate in the vicinity of Slateford and opposite on the New Jersey side. Because this section begins essentially at the entrance of the Gap, nothing further need be said of the stratigraphy of the Martinsburg or of the older limestones of the Ordovician. For those interested in these particular units, the recent contributions by Behre (2), B. L. Miller (14), Miller and Fraser (16) and R. L. Miller (17, 18) may be consulted.

The Ordovician system needs no more comment except to state that, although its contact with the overlying, basal Silurian, the Shawangunk formation, is not exposed at the Water Gap, it is doubtless an unconformity (22, 23, 34). Such a deduction is drawn from observations of exposures of this contact from Otisville, N. Y., west to the

Figure 4. Ordovician-Silurian uncomformable contact on the Erie Railroad to Otisville, New York. Photograph by Bradford Willard

Susquehanna Valley. Only on the Susquehanna are the formations disconformably related. At the other places, the angle of divergence varies from a few degrees to practically a right angle. The uppermost Martinsburg beds are supposed to be of Eden age, but direct proof is lacking. Westward, Eden fossils occur at the top of the shales at the

Figure 5. Ordovician-Silurian unconformity at Lehigh Water Gap. Photograph by Geo. H. Ashley

contact with the Silurian. In New Jersey the highest faunules recorded (32) appear to be somewhat older. Pulaski fossils are known from the Ordovician in eastern Pennsylvania (23), but not at the Ordovician-Silurian contact.

SILURIAN SYSTEM

The Silurian system in eastern Pennsylvania has been discussed most fully by Swartz and Swartz (26, 27), and the following remarks are based chiefly upon their work. The system here is divisible broadly into four units, the Bossardsville, Poxono Island, Bloomsburg and Shawangunk, in descending order. The Keyser of the Helderberg group, as at present designated, is not improbably assignable to the Silurian. This designation awaits final committment by Frank M. Swartz and others better versed in the stratigraphy and correlations of the Upper Silurian and Lower Devonian units. The Shawangunk lends itself to a certain degree of subdivision, but this is not essential in the description of so restricted an area, although mention of it will be found under the remarks on the succession along the Lehigh. The total thickness of the Silurian system is slightly more than 4,000 feet.

Shawangunk formation (Medina of Second Survey authors). The Shawangunk formation is well exposed on the Pennsylvania side. The lowest 450 to 500 feet of the formation, whose total thickness is of the order of 2,000, consists of massive, quartzitic, dirty gray sandstone and pebble beds whose phenoclasts are of white quartz, fairly well-rounded and sorted. Occasional larger quartz pebbles are found, and a few black shale fragments or clay galls occur. Beds of conglomerate are present where the pebbles have been sufficiently concentrated. In this part of the Shawangunk, at the turn of the highway on the Pennsylvania side of the Gap, there were formerly exposed a few black shale interbeds, remnants of which still remain after road-widening. At this place in these beds eurypterid remains are preserved in a fragmentary state. Here, in 1922, I collected *Hughmilleria shawangunk,* and it appears that this is the locality from which Clarke and Ruedemann (3) reported the following faunule:

Dolichopterus otiseus Clarke
Eurypterus maria Clarke
Styloneurus cf. *myops* Clarke
Hughmilleria shawangunk Clarke
Pterygotus cf. *globiceps* Clarke and Ruedemann

Near the same zone, but on the New Jersey side, Schuchert (22) recorded an occurrence of *Arthrophycus alleghaniensis,* but I personally have never had the good fortune of finding this fossil at Delaware

Water Gap on either side, nor do Swartz and Swartz (26, 27) report it. It should, however, be present, and is common farther west.

The remainder of the Shawangunk is similar to the lower part, but almost devoid of prominent pebble beds. The rather coarse, gray sandstone is usually quartzitic, and it may have a greenish cast. Throughout, the Shawangunk is heavy-bedded and well-jointed perpendicular to the stratification. It appears to grade up into the Bloomsburg by a transition of alternating red and gray beds. But all above the first red beds is logically placed by Swartz and Swartz in the Bloomsburg, a practice in accord with my own concepts as applied to analogous Devonian "transitional" beds (40).

Bloomsburg continental facies (High Falls of New Jersey Geological Survey, Clinton of Second Survey authors). The 1,800 to 1,900 feet of the Bloomsburg continental facies ("formation"), is dominated by comparatively soft, deep-red shale and sandstone. Of this sequence a practically complete section may be seen on the highway and the railroad on the Pennsylvania side of the Delaware from Delaware Water Gap village south. Beds of gray or greenish-gray sandstone are not at all rare, and in its lower 150 to 200 feet appear gray sandstone and conglomeratic strata very like those of the Shawangunk. The formation is barren, but contains occasional pseudofossils, principally ripple marks and mud cracks.

Poxono Island formation. I. C. White (33) described from farther up the Delaware Valley a formation which he named the Poxono Island shale. At best, it is unsatisfactorily developed and exposed in the type locality. Presumably, it continues southwest into the Water Gap section, and it has been identified with certain non-red, sandy beds above the Bloomsburg, with which it probably interfingers. The Poxono Island is more truly a sandstone than a shale, and may contain limy strata. The rock is brown or gray-green and weathers to a dark, rusty-brown hue. Exposures are to be seen at Delaware Water Gap village, where these relatively massive beds dip north under Cherry Valley. No fossils are known from the Poxono Island. An estimate of its thickness is unsatisfactory, but it is probably of the order of 300 feet or perhaps more.

Bossardsville limestone. The Bossardsville limestone was named by I. C. White (33), and is the highest undisputedly Silurian unit recognized in our section, according to present usage which places the Silurian-Devonian boundary at the top of the Bossardsville. It is probably about 100 feet thick, but its basal contact with the Poxono Island is concealed under Cherry Valley. The rock is a "ribbon" limestone, very similar in lithology to the Tonoloway of central Pennsyl-

vania. This similarity and the abundance of *Leperditia "alta"* in both are significant criteria for correlating the Bossardsville with the Tonoloway and thereby assigning the former to the highest Silurian. The "ribbon" character of the limestone may be seen to advantage in an abandoned quarry at the southeast tip of Godfrey Ridge. Here *Leperditia* is abundant.

The Silurian-Devonian contact is still a bone of contention in Pennsylvania. Swartz and Swartz drew it between the Bossardsville or the Tonoloway and succeeding, basal Helderberg formation, the Keyser limestone, in whose lower part *Chonetes jerseyensis* appears. In New Jersey the similar occurrence is known in the so-called Decker limestone (32). An apparently minor physical break below the Keyser (Decker) occurs in the Delaware Valley, but it may be local, that is, marginal, and of little significance.

DEVONIAN SYSTEM*

Although resembling the Silurian, the stratigraphy of the Devonian system in northeastern Pennsylvania is far more complex. The lowermost Devonian is largely limestone, the Helderberg group, followed by the Oriskany sandstone. This is, in turn, capped by the Onondaga group terminating in a prominent limestone. The Hamilton group of shales and sandstone, black below, gray above, of marine origin throughout, succeeds the Onondaga. In middle Portage time, following marine conditions, the continental Catskill facies invaded the region. This continental displacement of marine beds through westward off-lap, which is in many respects analogous to the behaviour of the Bloomsburg of the Silurian, will be apparent when individual units are discussed. Approximately 8,000 feet of Devonian strata are included in the combined sequences on the Delaware and Lehigh Rivers.

Helderberg Group

The lowest part of the Lower Devonian is a sequence of some 450 to 500 feet of dominantly calcareous beds designated as the Helderberg group (25). In the Delaware Water Gap region several divisions are recognized. The group rests in probable disconformity upon the Bossardsville and is succeeded by the Oriskany. In eastern Pennsylvania the Helderberg group is usually divided into the following units:

Port Ewen-New Scotland shale
Coeymans limestone
Keyser limestone

* Most of what is here said regarding the Devonian system is summarized from my report on the Devonian of Pennsylvania, in preparation with the Pennsylvania Topographic and Geologic Survey, 1938.

Keyser limestone. As already observed, the Keyser limestone is perhaps of Silurian age. It is here treated for convenience with the Helderberg group, that is, in the conventional manner hitherto in use in Pennsylvania. The Keyser of eastern Pennsylvania probably is largely equal to the Decker limestone of New Jersey (32), with *Chonetes jerseyensis* common to both. The beds are best seen a short distance east of our section near Croasdale Manor. There the exposed lower part consists of what F. M. Swartz calls (letter of April 14, 1938) the Decker sandstone member. It is medium-bedded, sandy limestone and limy sandstone, partly conglomeratic. Interbeds of impure limestone occur. *Chonetes jerseyensis* is present in this member. On the Erie Railroad east of Godfrey Ridge, the higher Keyser beds are not well exposed. They are observable on the highway one-quarter mile south of Shawnee-on-Delaware. Swartz recognizes in the upper 31 feet the Manlius limestone member which is thick-bedded and crystalline and contains *Stropheodonta varistriata* and *Spirifer vanuxemi.* Below this he reports 7½ feet of Rondout limestone, a dolomitic (?) member, buff-weathering. This was referred to as the Pethstone by earlier writers.

A complete faunal list for eastern Pennsylvania has not been compiled as yet for the Keyser or its members. However, Weller (32) compiled a table of 48 species from the Decker (Decker Ferry) limestone of New Jersey, which, by the way, he assigned to the Silurian. His list is quoted as follows:

DECKER LIMESTONE FAUNA, after Weller

Diphyphyllum integumentum Barrett
Prismatophyllum inequalis (Hall)
Favosites corrugatus Weller
F. pyriformis (Hall)
Uladopora rectilineata Weller
Halysites catenularia (Linnaeus)
Monotrypa corrugata Weller
Ptilodictya frondosa Weller
Escharopora siluriana Weller
Pholidops ovata Hall
Stropheodonta bipartita (Hall)
Leptaena rhomboidalis (Wilckens)
Orthothetes interstriatus (Hall)
O. deckerensis Weller
Chonetes jerseyensis Weller
Orthis flabellites Foerste
Dalmanella postelegantula Weller
Rhipidomella preoblata Weller
Pentamerus circularis Weller
Rhynchonella deckerensis Weller
R. agglomerata Weller
Wilsonia globosa Weller
Atrypa reticularis (Linnaeus)
A. lamellata Hall
Spirifer vanuxemi var. *minor* Weller
Cyrtina magnaplicata Weller
Reticularia bicostata (Vanuxem)
Rhynchospira famosa Hall
Whitfieldella nucleolata (Hall)
Edmondia deckerensis Weller
Pterinea emacerata (Conrad)
Pteronites? subplana (Hall)
Ptychopteria? subquadrata Weller
Actinopteria reticulata Weller
Mytilarca obliqua Weller
Proetus pachydermatus Barrett
P. depressus Weller
P. spinosus Weller
Calymene camerata Conrad
Dalmanites aspinosa Weller
Lepterditia altoides Weller
Beyrichia sussexensis Weller
B. barretti Weller
B. perinflata Weller
B. jerseyensis Weller
B. nearpassi Weller
B. deckerensis Weller
Bythocypris nearpassi Weller

Coeymans limestone. The second or middle division of the Helderberg group is the Coeymans limestone which attains a thickness of over 40 feet in our section (base hidden) and thickens eastward. These beds are exposed on the Erie Railroad east of the end of Godfrey Ridge. Swartz assigns the upper 14 feet to the Stormville sandstone member, a sandy limestone with interbedded sandstones and grits. Below, comes in a crystalline limestone which may be somewhat sandy and carries great numbers of *Gypidula coeymanensis* (*Gypidula glœata* of authors).

As with the Keyser, so with the Coeymans, no complete faunal list for the Delaware Water Gap section is available. I therefore quote again from Weller (32) who recorded from Flatbrookville, New Jersey, the locality nearest to Pennsylvania, the following forms:

COEYMANS LIMESTONE FAUNA, after Weller

Stropheodonta varistriata (Conrad)
S. variastriata var. *arata* Hall
S. planulata Hall
S. indenta (Conrad)
Strophonella punctulifera (Conrad)
Orthothetes interstratus (Hall)
Leptaena rhomboidalis (Wilckens)
Schizophoria bisinuata Weller
Gypidula glœata (Dalman)
Rhynchonella altiplicata Hall
Uncinulus mutabilis (Hall)
U. nucleolatus (Hall)
Atrypa reticularis (Linnaeus)
Spirifer cyclopterus Hall
S. macrupleurus (Conrad)
Meristella laevis (Vanuxem)
Rhynchospira famosa (Hall)
Lichenalia torta Hall
Fenestella, sp. undet.
Actinopteria communis (Hall)
Tentaculites elongatus Hall
Dalmanites pleuroptyx (Green)
Phacops, sp. undet.

Port Ewen-New Scotland shale. The highest of the Helderberg group is the Port Ewen-New Scotland shale which F. M. Swartz recognizes in the Delaware Water Gap section on the Erie Railroad east of Godfrey Ridge. He describes it as follows (letter of April 14, 1938):

"Calcareous and siliceous ash gray shale, 193 feet, above; impure siliceous limestone and interbedded chert, 33 feet, below; partly concealed. The lower 33 feet constitute the Kalkberg member of Chadwick. This member contains a *Spirifer macropleurus* fauna. *S. macropleurus* occurs in the next higher 40 to 50 feet of beds at Decker Ferry. I did not find it in abundant faunas collected in the upper 90 feet of the shale at Experiment Mills. The upper part of the shale at Experiment Mills appears to be Becraft and Port Ewen age."

Weller listed a small fauna from Flatbrookville, N. J., the nearest locality to Pennsylvania, and this (32) is quoted as we have no complete list for the Delaware Water Gap region.

NEW SCOTLAND FAUNA, after Weller

Streptelasma strictum Hall
Stropheodonta beckei Hall
Leptaena rhomboidalis (Wilckens)
Orthostrophia strophomenoides (Hall)
Rhipidomella oblata Hall
Eatonia medialis (Vanuxem)
Spirifer macropleurus (Conrad)
Meristella laevis (Vanuxem)
Dalmanites pleuroptyx (Green)

It may be observed that the upper part of the New Scotland, as here used, embraces part at least of what I. C. White (33) designated as the Stormville shales. F. M. Swartz now limits that term to the upper part of the Cocymans.

Oriskany Group (undifferentiated)

In central Pennsylvania the Oriskany group is composed of two formations:

Ridgeley sandstone
Shriver chert

In the preceding paragraph, attention was called to a suggested equivalence of the Stormville shale to the more western Shriver. If this were so, then the Oriskany would be fairly complete in the east. If, however, as Cleaves contends, this is not true, there is no lower Oriskany in the Water Gap region. He reports (personal communication and 4) that there is no Shriver fauna hereabout. The sandstone which here represents the Oriskany is merely the upper part of the group and presumably equals the Ridgeley. The Oriskany sandstone is fully exposed on Highway 611 up the south face of Godfrey Ridge and along Brodhead Creek at the east end of that ridge. Particularly noticeable is its outcrop on the Erie Railroad. Here, a very massive sandstone bed stands out vertically from the hillside as the "Devil's Backbone," quoting local vernacular. The highway cuts show its composition to be chiefly coarse to pebbly sandstone and dark chert bands. The sandstone on Godfrey Ridge has a recorded thickness of 50 feet.

The Oriskany beds are deeply pitted at many zones where fossil shells have been dissolved, leaving mere cavities. Only rarely are fossils well preserved, less seldom may they be collected satisfactorily owing to the hardness of the chert or the friability of the sandstone. The common Oriskany forms, *Spirifer arenosus* and *S. murchisoni*, are found. *Rensselæria ovoides* is rare, and *Hipparionyx proximus* is not known to occur here. Weller (32) listed several faunules from Oriskany localities in New Jersey.

Onondaga Group

I have recently revised the Onondaga group in Pennsylvania (41) and hold that two formations comprise it in Monroe County:

Buttermilk Falls limestone*
Esopus shale

* This is the cherty limestone originally correlated with the Onondaga of New York. It is now named for Buttermilk Falls on Marshall Creek, Monroe County (45).

These two formations are grouped together because of their close faunal relationships, their intergradational contact and their relations to subjacent and superjacent formations.

Esopus shale (Caudi-galli grit of early writers). The Esopus shale consists of not less than 250 feet of gray, brown-weathering, sandy shale. Because of its obscure bedding and its tendency to shear strongly under compression, a close measurement or even reliable approximation of its thickness is none too certain. For the same reason, obscure bedding and shearing tendency, fossils are rarely found.

Figure 6. Exposure of Oriskany sandstone on Highway 611 south of Godfrey Ridge. Photograph by Geo. H. Ashley

Nevertheless, a fauna indistinguishable from the rest of the Onondaga group is present. A good collecting ground is in highway cuts in Foxtown gap south of Stroudsburg. Some of the best exposures of the Esopus are along the Delaware, Lackawanna and Western Railroad on the north side of Brodhead Creek where it swings around the flank of Godfrey Ridge. On the Erie Railroad above North Water Gap station the sharp Esopus-Oriskany contact is exposed. This is typical of the disconformity between these two formations or their correlates throughout the State. The Esopus grades up into the Buttermilk Falls limestone. These relations show on the Delaware, Lackawanna and Western south of the East Stroudsburg station, and along Godfrey Ridge south of Stroudsburg. Everywhere, the dark, sandy shale grades up into the limestone by a gradual addition of more and more calcareous beds. It may readily be seen from these notes that the Esopus is not to be grouped with the Oriskany on any available criterion, but with the Onondaga cherty limestone, the overlying Butter-

milk Falls. I have elsewhere (41) listed the complete, composite fauna from the Esopus of eastern Pennsylvania and New Jersey. Most of the Pennsylvania fossils came from the Godfrey Ridge section. It is repeated here:

ESOPUS SHALE FAUNA

Favosites sp.
Taonurus sp.
Lingula sp.
Orbiculoidea sp.
Chonetes sp.
Spirifer sp.
Anoplotheca acutiplicata (Conrad)
A. concava (Hall)
Brachiopoda, undetermined
Palaeoneilo emarginata (Conrad)
Goniatites, undetermined
Dalmanites anchiops (Green)
Fucoids

Buttermilk Falls limestone. (Onondaga, Corniferous of authors.) Because of the elevation of the term Onondaga to group value, the name Buttermilk Falls limestone is introduced for those beds formerly designated as the Onondaga limestone. The formation in Monroe County is about 200 feet thick, and consists of heavily-bedded, dark or blue-gray limestone. The rock contains nodules and lenses of dark chert, most abundant in the middle of the formation, but decreasing in the upper and lower beds as these pass over respectively into the Marcellus and Esopus formations. The Buttermilk Falls limestone crops out low down on the north side of Godfrey Ridge, at various places in the vicinity of the Stroudsburgs, along the railroads south of those boroughs, and in nearby abandoned quarries (14). Because of the abundance of chert, fossils are obtained with difficulty. A faunal list from the region appeared in my recent paper on the Onondaga (41), and since it is quite representative of Monroe County and the Delaware Water Gap section, it is repeated.

BUTTERMILK FALLS LIMESTONE FAUNA

Zaphrentis simplex Hall
Z. sp.
Cystiphyllum sp.
Cyathophyllum sp.
Favosites sp.
Cladopora sp.
Corals, undetermined
"Crinoidea," columnals
Fenestella sp.
Leptostrophia perplana (Conrad)
Leptaena rhomboidalis (Wilckens)
Chonetes mucronatus Hall
C. sp.
Atrypa reticularis (Linnaeus)
A. spinosa? Hall
Cyrtina hamiltonensis Hall
Anoplotheca acutiplicata (Conrad)
Pentagonia unisulcata (Conrad)
Conocardium sp.
Platyceras sp.
Tentaculites bellulus Hall
Phacops bufo? (Green)

Hamilton Group

The Hamilton group in eastern Pennsylvania is very nearly like the New York type (5). It is divisible faunally into much the same units. However, the divisions are less clear-cut lithologically in Pennsylvania than in New York, and for this reason I am inclined to refer to our Moscow, Ludlowville and Skaneateles correlatives not as formations, but as faunal facies, designating all three as the Mahan-

tango formation, an inclusive term which I introduced for the upper Hamilton in central Pennsylvania (37). Below the Mahantango is the Marcellus formation.

Marcellus formation. In Monroe County the Marcellus formation of the lower part of the Hamilton group is between 800 and 900 feet thick. Most of this rock is very finely arenaceous, dark gray, non-fissile; the bedding generally is obscured. The rock often exhibits a sub-conchoidal fracture and may carry bands of small concretions. This phase is named the Brodhead Creek member as it shows well in Brodhead Creek Valley, Monroe County. Black, more or less fissile shale is encountered chiefly in the lower part of the Marcellus and is correlated with the Shamokin black shale (37) of central Pennsylvania. These two lithologic types suggest respectively the "Cardiff" and Chittenango shales of New York (5). The Shamokin black shale is transitional with the top of the Buttermilk Falls limestone as exposed along the south side of the Stroudsburgs in McMichael Creek and on the Erie Railroad, for example. The Brodhead member is well exposed in a quarry in the north side of Stroudsburg and beyond up Highway 90 along the west bank of Brodhead Creek. No fossils are recorded from the Shamokin black shale here, but the Brodhead member is very fossiliferous in some places; in fact it carries the largest fauna known from the Marcellus in Pennsylvania. This I have listed (35, 46), but repeat it here:

MARCELLUS FAUNA FROM STROUDSBURG

Bryozoa, undet.
Lingula cf. *delia* Hall
L. ligea Hall
Orbiculoidea sp.
Craniella cf. *hamiltoniae* Hall
C?
Chonetes mucronatus Hall
C. scitulus Hall
C. setiger (Hall)
Strophalosia truncata (Hall)
Camarotoechia prolifica Hall
Liorhynchus limitare (Vanuxem)
L. laura (Billings)
L. laura (?) (Billings)
Tropidoleptus carinatus (Conrad)
Spirifer mucronatus (?) (Conrad)
Ambocoelia umbonata (Conrad)
A. nana Grabau
Brachiopod, indet.
Panenka costata Hall
Nuculites triqueter Conrad
Liopteria laevis Hall
Lunulicardium curtum Hall
Actinopteria muricata Hall
Nyassa subulata Hall
Aviculopecten invalidus Hall
A. scabridus Hall
Allocardium alternatum (?) Hall
Modiomorpha alta (Conrad)
Styliolina fissurella (Hall)
Nephritoceras bucinum (Hall)
Bactrites cf. *clavus* Hall
Homalonotus decayi (Green)
Phyllocarid, indet.

Mahantango formation. The Marcellus grades up into the Mahantango formation so that only by their respective faunas may they be distinguished. There are about 1,200 feet of Mahantango beds. The lower 500 feet is dark gray shale and shaly sandstone and carries a fauna which assigns it to a place approximately equivalent to the Skaneateles (46) of New York:

SKANEATELES FAUNA FROM MAHANTANGO FORMATION

"Crinoidea," columnals
Atrypa reticularis (Linnaeus)
Spirifer granulosus (Conrad)
S. mucronatus (Conrad)
S. angustus Hall
Grammysia arcuata (Conrad)
Cephalpod, indet.
Phacops cf. *rana* (Green)
Greenops boothi (Green)

The next higher 500 feet of the Mahantango is chiefly dark-gray sandstone and shale. At its base is a coral reef of prominence (42, 46) from Monroe County westward. It is extraordinarily fossiliferous. These beds, beginning with the reef, are correlated with the Ludlowville of New York. The coral reef is believed to represent the Centerfield limestone of New York. The following fossils are known from it:

CENTERFIELD CORAL REEF FAUNA

Receptaculites (?) sp.
Streptelasma rectum (Hall)
Zaphrentis prolifica Billings
Z. simplex Hall
Z. sp.
Aulacophyllum sp.
Crasspidophyllum archiaci (Billings)
Ceratopora jacksoni Grabau
Syringopora maclurei? Billings
Favosites hamiltoniae Hall
F. clausus Rominger
Corals, undet.
Crinoid, undet.
"Crinoidea," columnals
Hederella? sp.
Monticulipora sp.
Fenestella biseriata? Hall
F. laevinodonta? Hall
F. parallela Hall
F. sp.
Thamniscus sp.
Bryozoa, undet.
Stropheodonta demissa (Conrad)
Leptostrophia perplana (Conrad)
Chonetes mucronatus Hall
Productella spinulicosta Hall
Dalmanella sp.
Rhipidomella vanuxemi Hall
Camarotoechia sp.
Tropidoleptus carinatus (Conrad)
Atrypa reticularis (Linnaeus)
Spirifer angustus Hall
S. mucronatus (Conrad)
S. granulosus (Conrad)
S. audaculus (Conrad)
S. sculptilis Hall
S. divaricatus Hall
Elytha fimbriata (Conrad)
Vitulina pustulosa Hall
Athyris spiriferoides (Eaton)
Brachiopod, undet.
Aviculopecten sp.
Modiomorpha concentrica. (Conrad)
Glyptodesma erectum (Conrad)
Actinopteria sp.
Turbo sp.
Phacops rana (Green)
Greenops boothi (Green)
P. sp.
Plantae, fragments

The highest Mahantango, about 200 feet thick, is dark, platy sandstone and shale with a rather restricted fauna (46). It is correlated with the Moscow of New York, approximately. Fossils are fewer in the Moscow portion than in the Ludlowville facies. A sample fauna is quoted:

UPPER MAHANTANGO FAUNA

Zaphrentis cf. *simplex* Hall
Aulopora sp.
Ceratopora jacksoni Grabau
"Crinoidea," columnals
Fenestella sp.
Leptostrophia perplana (Conrad)
Chonetes sp.
Camarotoechia cf. *prolifica* Hall
Spirifer mucronatus (Conrad)
S. sp.
Ambocoelia umbonata. (Conrad)
Athyris spiriferoides (Eaton)
Nucula bellistriata (Conrad)
Pterinea flabellum (Conrad)
Platyceras auriculatum Hall
Phacops sp.

Portage Group

In central Pennsylvania the Portage group is divisible into several stratigraphic units (38). Traced east, these gradually disappear. The Tully limestone (39, 44) passes over laterally into the Burket black shale (Genesee of authors), which is now known to extend as far east as western Monroe County. There, following the example of other Portage shales farther west, it passes over into sandstone. Consequently, in Brodhead Creek Valley, the marine Portage is represented entirely by sandstone. The group in eastern Pennsylvania is partly continental, or, putting it conversely, the Catskill facies displaces beds of middle and late Portage ages in Pike and Monroe Counties (36, 38, 40).

Trimmers Rock sandstone. The marine Portage outcropping along Brodhead Creek Valley consists of about 1,000 feet of brown, gray or greenish-gray sandstone called the Trimmers Rock (38). Bedding usually is heavy, and the rock commonly has a gnarly appearance. Fossils are not abundant, but a sparse "Ithaca" fauna is present. At the base of the Trimmers Rock exposed in cuts at the juncture of Highways 90 and 190, close to 50 feet of fossiliferous sandstone bears a faunule remarkable in that it contains *Hypothyridina venustula* and other elements suggesting the Tully or more truly the Laurens member of eastern New York (5, 38, 44). Because of this occurence, it is here possible clearly to differentiate the basal Portage from the underlying Hamilton. The complete Laurens faunule is:

LAURENS FAUNULE, BASAL TRIMMERS ROCK

"Crinoidea," columnals
Fenestella sp.
Rhipidomella vanuxemi Hall
Camarotoechia orbicularis (Hall)
C. eximia (Hall)
Liorhynchus mesacostale (Hall)
Hypothyridina venustula (Hall)
Tropidoleptus carinatus (Conrad)
Spirifer mucronatus var. *posterus* Hall and Clarke
S. sp.
Echinocoelia ambocoelioides Cooper and Williams
Pleurotomaria capillaria Conrad

Prosser (20) reported higher Portage faunules, and I have collected the following from the Trimmers Rock sandstone south of Analomink, although I have been unable to verify Prosser's reported two species of marine fossils from the Delaware River flags above the Analomink red shale.

TRIMMERS ROCK FAUNA (POST-LAURENS)

Douvillina cayuta (Hall)
Camarotoechia eximia (Hall)
Spirifer mucronatus var. *posterus* Hall and Clarke
Grammysia sp.
Leptostrophia rogersi Hall
L. sp.
Leda obscura? Hall
L. diversa Hall
Modiomorpha tioga Hall
Paracyclas sp. nov.
Pelecypod, undet.
Cyclonema sp.
Pleurotomaria sp.
Echinocaris cf. *multinodosa* Whitfield

Catskill Continental Facies

Here, as in my recent writings, I use the term Catskill as a facies designation applied to all non-marine beds of the Devonian (40). Because of this use, the basal Catskill strata may be of very different ages among several localities. In the vicinity of Analomink, the advance guard of the Catskill facies appears in the middle Portage. Thence, upward and northward, the remaining Devonian is made up entirely of continental strata as far as I can determine. These are divisible into units (40), only part of which need be discussed at any length here.

Analomink red shale. Named from the type locality at Analomink (40), the continental Analomink red shale there overlies the Trimmers Rock sandstone and ushers in the Catskill facies. This lowest unit of the continental Devonian is about 100 feet thick, barren, and of comparatively local development as it is not known to extend much beyond Pike and Monroe Counties.

Delaware River flags. Above the Analomink red shale is about 1,000 feet of greenish, flaggy sandstones, the Delaware River flags, originally named by I. C. White (33). They closely resemble the Trimmers Rock sandstone in lithology, though on the average usually somewhat greener. Nevertheless, these are essentially all continental beds in Monroe County. That their age is Portage may be determined and demonstrated by tracing them westward across the Lehigh Valley and noting that they gradually assume, through lateral transition, a marine facies with "Ithaca" fossils, and so blend and fuse with the Trimmers Rock sandstone as the Analomink dies out between. I have found no marine fossils in the Delaware River flags along Brodhead Creek Valley and eastward, but they appear in the Wind Gap section, as will be noted in the itineraries.

Above the Delaware River flags there is a thick sequence of alternate red and green or gray, wholly continental units, all assigned to the Catskill facies and all of Chemung age or younger. Their chronologic positions are established by actual tracing of important units westward into contemporaneous, marine beds of established age and correlation. These later Catskill units are all beyond the northern limits of the Delaware Water Gap section as here used, so that details of them are omitted. In the supplementary, detailed itineraries, mention is included of some of the higher units, particularly the gray Honesdale sandstone. The Mississippian and Pennsylvanian formations are embraced in the Lehigh section. For details of these upper formations, my recent work on the Catskill may be read (40).

PLEISTOCENE AND RECENT

It is not the purpose of this report to enter into any prolonged description of such unconsolidated sediments of the Delaware Water Gap region as are assignable to the Pleistocene and Recent epochs. Nevertheless, since interest has newly been aroused in these deposits which are the next in age preserved in the area following the Devonian, reference will be made to them, but detailed data must be taken from accounts such as those of Leverett (12) and Ward (30, 31). Of particular interest, however, are a few outstanding points. In Brodhead Creek Valley between Analomink and East Stroudsburg is a broad, flat of fluvial or glacio-fluvial origin. It seems not unreasonable to suppose that much of this sand and gravel was dumped here as the creek freed itself from the confines of the relatively narrow, rocky valley cut in the harder Portage and later beds to the north. The gravels may be seen along Highway 190 north from East Stroudsburg where they have been dug in recent years, as at Gravel Place, and also along the abandoned Delaware Valley Railroad. Similar in origin, but built on a considerably grander scale, are the beds of very coarse gravel and boulders that spread south from the Water Gap. Doubtless they settled at this point when the river's velocity slackened as the stream, swollen with melting ice, debouched from the Gap in late Pleistocene time. In the vicinity of the confluence of Brodhead and Cherry Creeks with the Delaware River may be seen some clearly defined terraces. The Delaware, Lackawanna and Western tracks occupy one, the Highway 612 up Brodhead Creek from Delaware Water Gap village lies on a second, higher terrace, and a third, yet more elevated, fringes the foot of Godfrey Ridge. Besides these water-laid deposits, true till is probably to be seen, particularly in the northern part of the region in the more rugged country toward the Pocono Plateau. The nature of the deposits of Cherry Valley and of the low land west of Stroudsburg has not been fully ascertained, but both till and outwash probably occur.

STRUCTURAL GEOLOGY

The geologic structures in the Delaware Water Gap region are relatively simple. Gentle folding dominates. Some gravity faults are known, but overthrusts are few. There is evidence of transverse, tear faults with horizontal movements of adjacent blocks. Disconformities occur between the Oriskany and the Esopus and probably between the Keyser and Bossardsville. The Martinsburg-Shawangunk relations, I observed, probably are unconformable, though the angle of divergence of dip is not predictable at Delaware Water Gap as the contact is concealed.

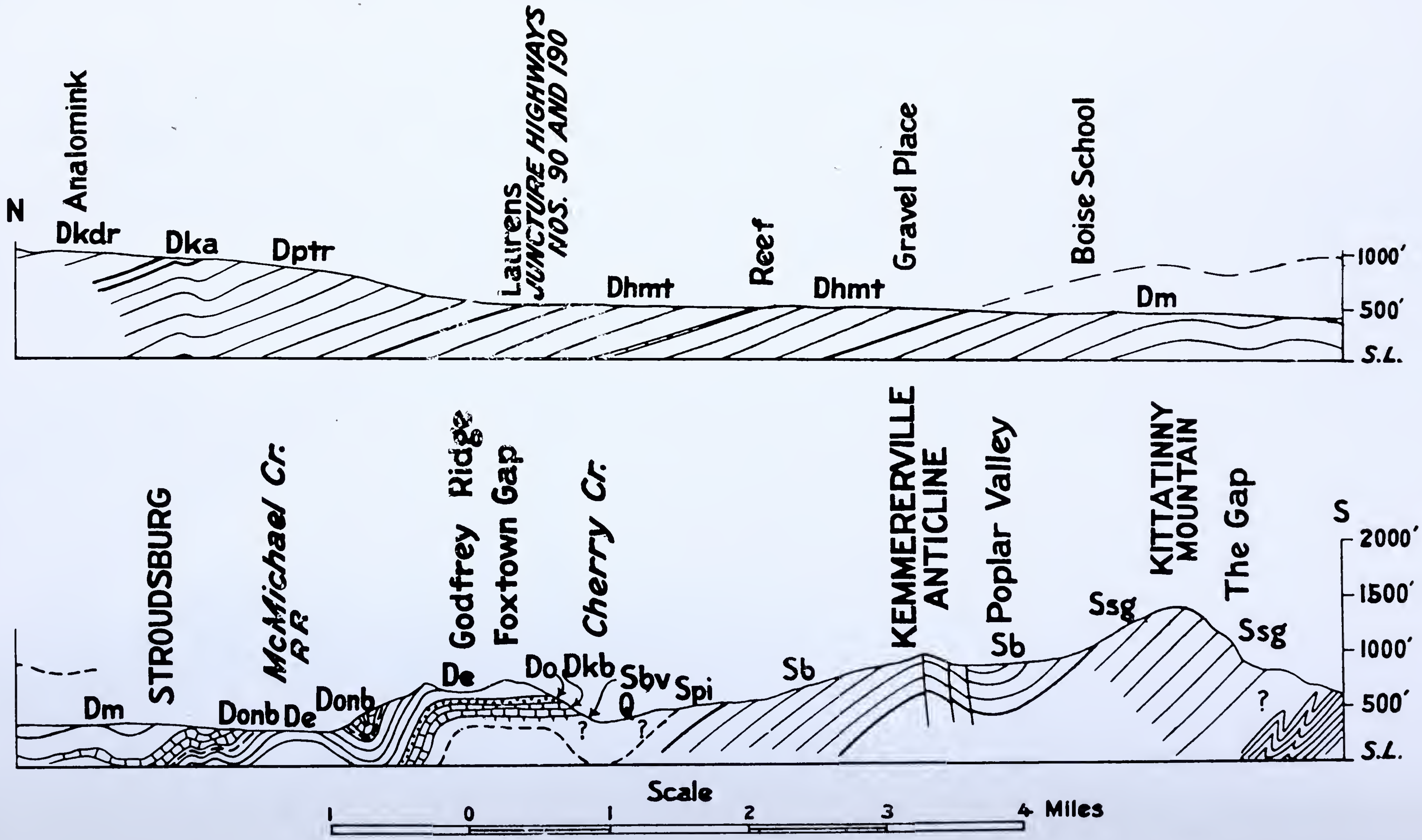

Figure 7. Geologic section from Delaware Water Gap to Analomink

The Shawangunk in Kittatinny Mountain is raised in a monocline, dipping fairly steeply north to pass under the Silurian red shales above the Water Gap. The Bloomsburg red beds are thrown into a gentle arch, the Kemmererville anticline. This fold is double-crested and broken near the crests by gravity faults presumably of small throw. The structure is best observed when the leaves are off the trees by one who looks from the Pennsylvania side across the river to the New Jersey shore. The structural relations of the higher Silurian units are obscure, and nothing can be finally determined anent these. Probably the Bossardsville and Helderberg limestones are bowed down in a broad syncline beneath Cherry Valley.

Along Brodhead Creek and the east end of Godfrey Ridge are certain remarkable structures. If one walks north along the Erie Railroad track from North Water Gap Station, the Lower and lower Middle Devonian formations are seen, steeply dipping (they stand almost vertically) in regular and uninterrupted sequence. Across the creek on the ridge, all along its southern slope, outcrops show the position of the Lower Devonian formations. Across the creek from the Erie Railroad section, the structure is quite unlike that on the railroad. Godfrey Ridge is an anticline overturned or slightly recumbent north. Along its south slope where the grade is steeper than the dip of the rocks southward, the Helderberg, Oriskany and Esopus are successively exposed from foot to crest. Nearly flat-lying Esopus caps much of Godfrey Ridge. The strong shearing of these beds is characteristic and seen to better advantage here than elsewhere in Pennsylvania.

As the north slope is reached at Foxtown Gap, the Esopus is flexed down suddenly and disappears in nearly perpendicular beds beneath the Buttermilk Falls limestone at the foot. A mile to the east of this Gap, a secondary "roll" complicates the structure. It is here that Godfrey Ridge anticline is truly recumbent. On the crest, near the east end of the ridge, the older beds appear from beneath the Esopus. These structures were more or less fully understood by Rogers (21) and White (33), and I myself have attempted to contribute a general figure of them (7). It appears that a north-south tear fault underlies the small water gap of Brodhead Creek at Minnisink Mills. On the east, the beds have been tilted, but not folded. On the west, they have crumpled in Godfrey Ridge anticline. The creek "found" and followed this zone of weakness. A similar north-south fracture is suggested at Delaware Water Gap. The topographic map (old edition including the New Jersey side) shows the crests of Kittatinny Mountain between the New Jersey and Pennsylvania sides to be off-set.

Godfrey Ridge displays a section which should not be finally dismissed without reference to the cleavage of the Esopus shale beds, particularly at Foxtown Gap. Careful observation of the attitude of the beds in relation to their cleavage, is a rather instructive study in structural interpretation.

GEOLOGIC HISTORY

Toward the close of the Ordovician, presumably in post-Eden time, eastern Pennsylvania was uplifted. An interval of weathering and perhaps peneplanation ensued prior to the opening of the Silurian. It seems, based upon reasonably sustained arguments, that there may have been at this time some compression and folding correlatable with the Taconic disturbance. However, as there is still opposition to this theory, it is unwise to offer final commitment at present. Certainly there was renewed elevation to the east in early Silurian days and concomitant depression toward the west. This tilting affected the accumulated debris of the late Ordovician interval of quiesence in that it was swept west and deposited as the Shawangunk and other early Silurian formations, believed to be largely marine in nature in Pennsylvania (34). Accumulating sediments next filled the sea. These sediments thin away into central Pennsylvania and pass over into marine beds with diagnostic Silurian fauna (24, 26, 27). The origin of the Poxono Island formation is probably similar to that of the Bloomsburg, but its local liminess suggests that it may be in part marine. The closing stage of the Silurian sedimentation indicates a brief marine incursion during the deposition of the Bossardsville limestone.

The Silurian-Devonian break is slight if indeed there is actually a disconformity, be it at the bottom of the Keyser or the Coeymans. Some of the Helderberg is "abnormal," that is, tends to be clastic rather than calcareous. Local, or marginal unconformities are to be expected in such a sequence, laid down as it was near shore. At any rate, the sea remained during earliest Devonian time, but may have withdrawn briefly toward the close of the Helderbergian, with no Shriver present, to return with renewed vigor as the upper Oriskany sandstone formed. This probable absence of the Shriver is indicative of a pre-Oriskany hiatus. The Oriskany sandstone is assumed to represent the initiation of the great Devonian cycle of sedimentation or its first on-lap phase. A short break at the top of the Oriskany coarse sandstone and pebble beds is followed by the Esopus shale laid down in a muddy sea, which, clearing presently, produced the cherty Buttermilk Falls limestone. In this limestone we appear to witness the maximum incursion of the epeiric sea of the Devonian cycle. It and probably part at least of the Marcellus black shale facies are

more or less indicative of an interval of stillstand. From then on the sea receded. The last traces of a marine environment left the area for good and all about middle Portage time when the first continental displacement of marine beds is expressed in the Analomink red shale succeeded by superjacent units of the Catskill facies.

Possibly most of the post-Ordovician structures, if not all the folds and faults of the Delaware Water Gap region, originated during the Appalachian revolution. There is no proof of folding here at the close of the Devonian (Acadian disturbance). Nevertheless, some scepticism haunts the concept of attributing to the Appalachian revolution all of the structures. Those who claim to champion the cause of the Taconic disturbance in Pennsylvania see two major intervals of folding. Others explain the Ordovician-Silurian structural contact as due to crushing of the weak shales beneath the competent Shawangunk sandstones and conglomerates during the Appalachian revolution. Although the Taconic concept appears the more reasonable, certainly the more readily applied, the final choice is still to be made.

How many cycles of uplift, erosion and peneplanation succeeded the Appalachian revolution is a controversial question which must be referred to the geomorphologist. In a similar category is the question of rhythmic continental glaciation and its deposits. Not that glaciation is to be ignored or its effects belittled. The controversy is merely how many times the ice may have invaded and deserted the area, in which direction or directions did it move, and which deposits are finally to be assigned to each successive stage of Quaternary ice invasion and retreat.

COMPARATIVE SECTIONS

Along the southern boundary of Monroe and southeastern Carbon Counties, cutting through Kittatinny Mountain, are several other gaps besides that of the Delaware. All of these are wind gaps except that on the Lehigh. Most of the wind gaps are small and unimportant and show little or nothing about the stratigraphy and structural relations. However, the section at Wind Gap itself is significant. A brief description of this and the sequence along the Lehigh River from the Lehigh Water Gap north follows.

Wind Gap section. From the Wind Gap north through Saylorsburg, Brodheadsville, Effort and north to the Pocono Plateau, a fairly complete sequence can be seen. The Silurian is essentially the same as on the Delaware, save for the probable absence of the Poxono Island formation. The well-exposed Bossardsville limestone on the ridge southwest of Saylorsburg presumably rests directly upon the red Bloomsburg shale. In this ridge the Oriskany appears to be

faulted into contact with the Bossardsville. The limestone is exposed in quarries along the south flank and the crest. Immediately north of these quarries on the crest an old iron ore pit exposes what I take to be fragments of Oriskany sandstone. If so, then the Helderberg is cut out by a thrust. Oriskany or Oriskany-like sandstone crops out along the northern crest of this hill, here designated Chestnut Ridge, rather than Godfrey Ridge as its counterpart is to the east. A similar sandstone is found in the Lehigh and New England Railroad cut at Saylorsburg, and is nearly barren. It probably is Oriskany. Sandstone and chert of Esopus age are recognized farther west but with Oriskany lithology, and it is believed that these may be in part the higher beds seen on the ridge southwest of Saylorsburg. Unquestioned Oriskany float rock may be seen along the highway south of Chestnut Ridge below Saylorsburg, but the outcrop is now concealed.

The Onondaga and much of the Marcellus are concealed north of Saylorsburg. Then a splendid section, recently made available, is exposed on Highway 115 crossing synclinal Wier Mountain to Brodheadsville. The syncline brings down the Portage so that much of it and the upper and middle Mahantango formation are present. On the south limb the Centerfield coral reef is beautifully exposed as a mass of corals and other organisms. Along the north limb, the lower Portage beds crop out. The Laurens has not been identified here as yet, but I have seen a thin remnant of the Burket black shale (Genesee of authors). This is the farthest east that this member has so far been recognized in Pennsylvania. (White's Monroe County identifications (33) are all faulty). Above it, in dark shale, occurs a sparse Naples fauna, a novelty east of the Susquehanna Valley.

At Effort the Trimmers Rock sandstone is revealed in cuts and is quite fossiliferous. The Analomink red shale probably is vestigial north of the village. Above it rocks that would be called the Delaware River flags farther east, are here fossiliferous sandstones and so must be considered marine Portage rather than a unit of the Catskill facies. They are assignable to the Trimmers Rock. Still farther north, barren, gray to greenish-gray sandstones are of the true Delaware River flag type. Higher Catskill red beds are almost entirely concealed in this section under the broad, gently sloping fan built out from the Pocono Plateau escarpment by Pohopoco Creek. The escarpment itself along the Plateau displays the Honesdale sandstone in one of the best sections known of this unit. This massive, pebbly, gray sandstone was formerly mistaken for the Pocono of Mississippian age, but it has been shown on the contrary to belong to the relatively late Devonian sequence (40). It is succeeded by other red units which

separate it from the true Pocono formation exposed along the western border of the Pocono Plateau.

Lehigh Water Gap section (6). The sequence at Lehigh Gap differs in certain particulars from those to the east (16). Swartz and Swartz (27) recognized a Silurian succession beginning with beds which they designate as Tuscarora (457 feet) resting unconformably upon the Martinsburg. This lowest Silurian is of like lithology and ties in with the lower part of the Shawangunk at the Delaware. Above this comes in the Clinton, 1,093 feet, of gray, greenish and greenish-gray sandstones and some iron stones, but very little red. These beds appear to be the correlate of the upper part of the Shawangunk to the east. The Clinton is overlain by at least 1,168 feet (top concealed) of Bloomsburg red shale and sandstone.

The Helderberg is almost wholly concealed in this section as also is the Bossardsville, or, perhaps more correctly, the Tonoloway. The Oriskany and Onondaga groups have only recently been reinterpreted, largely through the studies of the Swartzes and Cleaves (28, 4). It was supposed until very recently that the Esopus thinned to a few feet above Palmerton, and that the Oriskany was exceptionally thick (41). It is now established upon paleontologic evidence that what had been called Oriskany, is actually only in part assignable to that group. Unquestioned, fossiliferous Oriskany is present, but it is a comparatively thin sandstone observable in the neighborhood of Palmerton and across the river along Lizard Creek Valley. Above it appears some 300 feet of sandy and cherty beds, the true Oriskany amounting to only about 50 feet. The lower part of these post-Oriskany sands, the Bowmanstown chert, carries a Middle Devonian fauna of Onondagan affinities. The upper part, the Palmerton sandstone, so far as known, is barren. Ascribing the Bowmanstown to the Esopus, it is evident that that formation retains more nearly its normal thickness, but changes lithologically westward from the Delaware Valley. Cleaves (personal communication) believes that these abnormal beds continue east to Little Gap. There, an interesting but structurally complicated section is recognized. I have suggested above that the Esopus sandstone may be present in the Wind Gap section and perhaps includes the white clay mined thereabout (10). The "clay" appears to be of Helderberg age only, according to Cleaves. The Onondaga is further abnormal in that it here (Lehigh Valley) includes in the lower part of the limestone a "paint ore" (8, 15, 41, 49). This unusual bed is highly fossiliferous (48).

Structures in the Lehigh section are more complex than to the east, and faulting is recognized at several points. Thus, along the north

side of Stone Ridge west of the river and Stony Ridge east thereof, the Oriskany or higher sandstones (Palmerton, Bowmanstown) are faulted against fossiliferous Marcellus black shale.

The Middle Devonian formations are exposed along the river from Bowmanstown north on the south limb of the syncline which brings down the Portage (Trimmers Rock) sandstone. An anticline at Lehighton raises the Hamilton again, so that the Centerfield coral reef is exposed at the west end of the old bridge at Lehighton. Dark shale north of Weisport is questionably correlated with the Burket. Continuing north through Packerton, the Catskill facies is well exposed on both sides of the river. The Honesdale gray sandstone appears in the first ridge above Packerton and may be studied along the highway in cuts north of Flagstaff (Mauch Chunk quadrangle). This is one of the best places to observe the distinction between the Honesdale and the lithologically similar but younger Pocono sandstone (29, 40). Separated by red beds, including red conglomerate (Pimple Hill, etc), the pair of massive, gray sandstones form the two crests of Second Mountain south and west of Mauch Chunk.

DETAILED ITINERARY

The following itinerary is intended as a guide to the section at Delaware Water Gap and northward along Brodhead Creek. The schedule is planned to start from the East Stroudsburg Teachers College campus. Thence it runs east along the north side of Brodhead Creek Valley and beyond to Buttermilk Falls on Marshall Creek. Here the route turns back to North Water Gap and Delaware Water Gap villages to follow the west side of the Delaware to the entrance to Delaware Water Gap. The route then retraces its course north along the Delaware, crosses Godfrey Ridge to Stroudsburg, and continues north along the west bank of Brodhead Creek to terminate at Analomink. All distances are approximate and from the campus of the Teachers College. The entire excursion is included on the Bushkill and Delaware Water Gap quadrangles. Supplementary data on the Wind Gap and Lehigh Water Gap sections are appended.

Miles

0.0 Start. East Stroudsburg Teachers College Campus. Proceed east on Highway 612 for 1.5 miles.

1.5 On Highway 612, following along the north side of the deeply entrenched Brodhead Creek Valley. Note Godfrey Ridge to the south. It is supported by hard, pebbly Oriskany sandstone and Esopus shale and sandstone of Devonian age. The Oriskany is the gas sand in Tioga County and the glass sand in Huntingdon County. This formation makes the "Devil's Backbone" to the east above the creek where it curves around the end of the ridge. Note the structure as displayed. The creek at our feet is cut in the softer Esopus shales, and we stand upon the cherty Buttermilk Falls limestone of the Onondaga group.

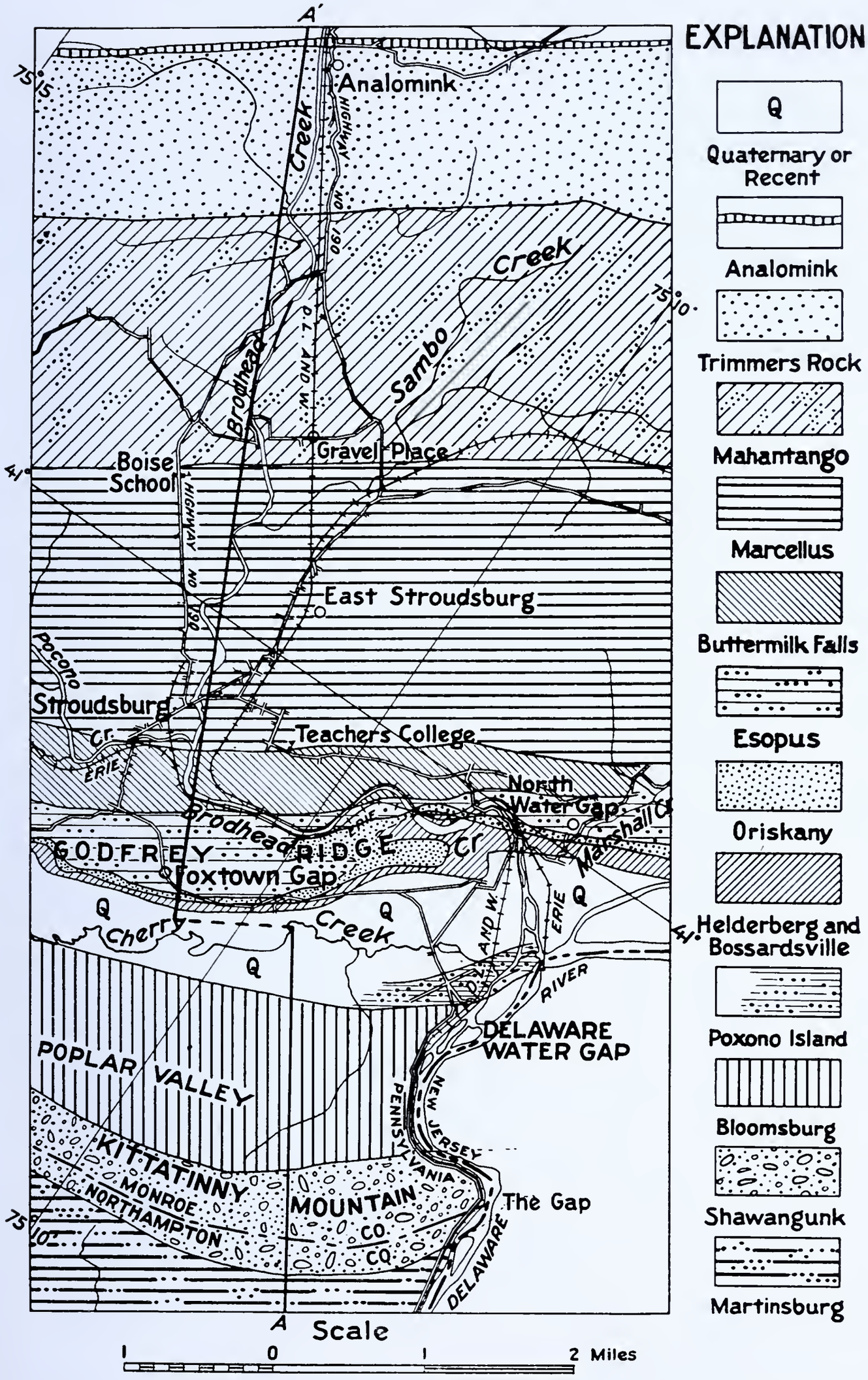

Figure 8. **Geologic map of Delaware Water Gap area** (Geology omitted in New Jersey).

Proceed east, keeping straight on where the road forks right to North Water Gap (*i. e.*, this is the old road to Delaware Water Gap). Continue east to Highway 402. Left up the valley of Marshall Creek to Buttermilk Falls.

2.9 Buttermilk Falls. Highway cuts and falls in creek over cherty Onondaga limestone. This is the type locality for the Buttermilk Falls limestone of the Onondaga. The rock is very hard, gray, massive and usually contains black flint nodules and bands. In many places it is fossiliferous. These beds overlie the Esopus shale which in turn rests upon the Oriskany on Godfrey Ridge. Compare the position of the Oriskany here with that observed in the "Devil's Backbone." At this point, about face and continue southwest along Highway 402 to its intersection with Highway 612. Turn left through North Water Gap and right across Brodhead Creek and Erie Railroad. Note terraces in fields beside the road between North Water Gap and Water Gap village.

4.5 Sharp turn left. Road is following one of the several terraces. The Delaware, Lackawanna and Western Railroad track is on a lower one. A higher terrace is at the right along the base of Godfrey Ridge. At this point a lane, right, leads to abandoned limestone quarry at east end of Godfrey Ridge, about three-quarters of a mile north of Delaware Water Gap village. The quarry is in the Bossardsville "ribbon" limestone, and the beds contain *Leperditia* in some abundance. Pebble beds at the top of the quarry face are assigned to the basal Keyser (Decker) formation.

If it is desired to observe the complete Helderberg, including the Keyser, in this vicinity, a good section is exposed along the Erie Railroad north from North Water Gap station. The Coeymans is also to be seen in the east end of Godfrey Ridge. Both these localities may be reached conveniently from the highway bridge across Brodhead Creek at North Water Gap.

Continue south through Delaware Water Gap village via Route 611 to the entrance of Delaware Water Gap.

7.3 Delaware Water Gap. Ample parking space is available immediately south of the entrance. The massive, gray Shawangunk conglomerate and sandstone support the ridges and form cliffs. Talus from their ledges covers the Shawangunk-Martinsburg contact. At the west at the turn of the highway, thin black shale lenses occur among the massive beds and carry sparse eurypterid fragments. *Arthrophycus* has been reported from the lower part of the Shawangunk in this region, but apparently is very rare. Note the off-set of the Kittatinny Mountain crest on opposite sides of the Gap.

Turn and go north along Highway 611.

8.2 Along the highway opposite and above the bath house (on New Jersey side), rock cuts expose the "transition" beds from the gray Shawangunk to the red and green Bloomsburg facies. As one continues north, looking across to the New Jersey side, particularly when the leaves are off, the Bloomsburg red beds are seen to rise in the double-crested, faulted, Kemmererville anticline. Glacial grooving is observable on the Pennsylvania side. To the northeast, the open, island-dotted, upper Delaware Valley is glimpsed, a strong contrast in physiography with the narrow, steep-sided valley and swift water at the Gap.

9.1 Site of burned Kittatinny Hotel on right. Entering south side of Delaware Water Gap village. The Bloomsburg beds grow brownish upward and sandy. These beds in the village are assigned to the Poxono Island formation and may be observed along the left (west) side of the main street and at the north end of the platform of the railroad station.

Continue north through the village, taking the left fork at traffic light.

10.0 Ascending the south slope of Godfrey Ridge above the valley of Cherry Creek. Extensive road cuts expose the sequence of Helderberg, Oriskany, and Esopus from the base upward. The coarse Oriskany sandstone and conglomerate are cherty in spots, but are all assignable to the Ridgeley. It and the Helderberg are fossiliferous

Figure 9. View of Delaware Water Gap from Godfrey Ridge at Foxtown Gap. Photograph by Bradford Willard

11.8 Refreshment stand and parking space at top of Godfrey Ridge. Looking back (see Figure 9), the water gap is seen to the southeast. The subsidiary ridge along the northern flank of Kittatinny Mountain is the Kemmererville anticline which we just crossed. At our feet is meandering Cherry Creek in a valley presumably underlain by Helderberg and late Silurian limestones. Here, at the crest of Godfrey Ridge along the highway, cuts expose the sheared Esopus formation. Continuing north, as the road turns left (west) and starts to descend the ridge, the Esopus may be seen again, and here careful observation reveals that it dips suddenly and steeply north. At this point the beds carry a sparse Onondaga fauna.

At the base of the ridge, the cherty Onondaga limestone stands vertically in a small exposure.

The structure of Godfrey Ridge may be observed further by walking along the Erie Railroad. In cuts beside the track it is possible to see clearly the position of the Onondaga limestone and its relation to the Esopus in the slightly recumbent north limb of Godfrey Ridge anticline. The Esopus is excellently exposed along the banks of Brodhead Creek, particularly on the Delaware, Lackawanna and Western Railroad near the hydro-electric station. The Esopus-Buttermilk Falls transition is splendidly illustrated on the D., L. & W. tracks in the first curve and cut south of East Stroudsburg station.

13.3 Continuing through Stroudsburg, cross Pocono Creek, turn right along principal street and then left at traffic light at curve into Highway 90.

Note: On McMichael Creek immediately south of this turn, the Onondaga-Marcellus transition is exposed at low water under the bridge. South of the bridge on the railroad, a cut in rather shaly, upper Onondaga limestone is an excellent place at which to obtain fossils.

Continuing north on Highway 90, turn left (west) on first street at top of slight rise at northern edge of town. Continue west about 200 yards to quarry. Here is exposed the slightly arenaceous, dark gray to black Marcellus shale. It is the most fossiliferous occurrence of this formation known in Pennsylvania. This is the type region for the Brodhead member of the Marcellus.

Returning to Highway 90, continue north along same up the west bank of Brodhead Creek.

16.2 On Highway 90 about two miles north of Stroudsburg, the road makes some angular turns east and north. Cuts expose the Centerfield coral reef of the middle Mahantango which here marks approximately the base of the Ludlowville. Vast numbers and a great variety of fossil organisms may be collected here.

Continue north on Highway 90.

17.5 Highway 90 crosses east over Brodhead Creek and the railroad and joins Highway 190 up the east side of the valley. At the juncture of the two highways, a cut exposes the lowest Portage beds recognized in this area. This is the basal Trimmers Rock sandstone, correlated with the Laurens member of New York because of the occurrence of Tully fossils in both. These occur in the lower few feet of the sandstone. No lower Portage beds are found in this section. Presumably, the Laurens rests directly upon the topmost Hamilton, but the contact is hidden.

Continue north along Highway 190.

17.5-18.5 Cuts along Highway 190 through Analomink expose the Trimmers Rock sandstone, which is marine but sparsely fossiliferous. At Analomink, red beds appear. This is the type locality for the Analomink red shale. Across the railroad and creek from the village there is a large, abandoned quarry in the higher sandstones. In the region north of Analomink to the escarpment of the Pocono Plateau bedrock is poorly exposed because of the glacial drift. Consequently, little is to be seen or said of this area. Those desiring to see more of these higher Catskill units should visit the Wind Gap and Lehigh Water Gap sections, notes on which follow.

Supplementary Trips

Wind Gap section

The points described in this section are in the Wind Gap and Pocono quadrangles. Starting from Wind Gap, the Shawangunk is exposed west of Highway 115. Descending the north slope of Kittatiny Mountain, the red Bloomsburg beds show in a few patches, but neither on the highway nor on the Lehigh and New England Railroad's branch line through the Gap to Saylorsburg are there good exposures. Looking north to Chestnut Ridge, the white scar of abandoned quarries in the Bossardsville limestone stands out. These may be reached by turning left on the first dirt road south of Saylorsburg.

At Saylorsburg, a railroad cut south of the forks of Highways 115 and 612 shows the massive sandstone which in part supports Chestnut Ridge and may be the Oriskany. Eastward along Highway 612 are clay mines (10). Continuing up Highway 115, a Devonian sequence may be followed.

Between Saylorsburg and Brodheadsville, the road cuts across Wier Mountain, a synclinal structure. At the south side there is a fine exposure of the Centerfield coral reef. Northward, the Hamilton-Portage relations are observable in cuts. At the north flank of the syncline, dark shales occur at the base of the Portage, and carry a few Naples organisms.

North of Effort, the Portage-Catskill sequence is encountered. In the village, highway cuts expose fossiliferous Trimmers Rock sandstone. These beds are to be seen northward at intervals, interrupted briefly at the north side of the town by a red band assumed to be the Analomink. Fossiliferous beds follow for a few hundred feet, indicating, if the red be the Analomink, that the succeeding Delaware River flags are passing over from the continental to the marine facies westward. Northward to the foot of the Pocono escarpment the higher Catskill beds are concealed. At the foot of the escarpment a high cliff and road cuts display the Honesdale sandstone to great advantage and probably as well developed as anywhere. It is here readily seen that the Honesdale is the chief element supporting the Pocono Plateau. On the plateau, higher red beds of the Catskill show along the road to Pimple Hill.

Lehigh Water Gap section

The Lehigh Water Gap section is in the Mauch Chunk quadrangle. At the entrance to the Lehigh Water Gap, complementary sections are exposed along the Lehigh and New England Railroad, the Lehigh Valley Railroad, the Central Railroad of New Jersey and Highway 309. Along the Lehigh and New England track at the east end of that railroad's bridge across the river, is one of those rare exposures of the Ordovician-Silurian contact. Here, the Martinsburg and

the basal conglomerate of the Tuscarora are beautifully exposed in sharp contact. The sections show the Tuscarora and Clinton to advantage. (It will be recalled that Swartz and Swartz (27) subdivide the Shawangunk on the Lehigh.) Continuing north along Highway 309 into Palmerton, the Bloomsburg red shale and sandstone are abundantly displayed.

The highest Silurian and lowest Devonian beds are almost entirely concealed. On Stony Ridge west of Palmerton and across the river in Stone Ridge, the Oriskany and succeeding sandstones of the Esopus with their associated chert beds are well exposed. Quarries and cuts make a study of these formations and the complicated structure hereabouts attractive. At Hazard is one of the paint ore mines which for years has extracted an iron-rich bed of the Onondaga limestone to burn for pigment. The dump of this mine is a well-known collecting locality for Onondaga fossils.

The section north from Stony Ridge crosses a broad, low syncline, the westward continuation of the structure of Wier Mountain mentioned in the Wind Gap section. It is here somewhat more deeply dissected by the transverse channel of the Lehigh, and along its axis the beds rise until they include the lower part of the Catskill continental facies. Hamilton and Portage fossiliferous strata are well exposed, but the structure is rather confusing, especially along the south limb where faulting has occurred. At Lehighton, the Centerfield coral reef is poorly represented at the bridgehead.

North of Lehighton through Packerton, the section on the highway passes up into the red Catskill. The Delaware River flags are nearly all marine here, but as no Chemung has been recognized as yet, they may be referred as a whole to the Trimmers Rock sandstone of Portage age. Perhaps the most interesting feature of this section is that observed in Second Mountain which reaches the river immediately south of Mauch Chunk. Its southern crest north of Packerton is supported by the Honesdale gray sandstone and conglomerate, and these are continued east across the river in Bear Mountain and the escarpment of the Pocono Plateau. The northern crest is the true Pocono of Mississippian age and is separated from the beds of the southern crest by red, higher Devonian strata that are quite conglomeratic. Mauch Chunk is the type locality for the Mauch Chunk red shale which is overlain by the Pottsville conglomerate and coal measures in Mt. Pisgah northwest of the town.

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